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The effect of pedalling cadence on skeletal muscle oxygenation during cycling

Journal:	<i>International Journal of Sports Medicine</i>
Manuscript ID	IJSM-08-2018-7146-pb.R2
Manuscript Type:	Physiology & Biochemistry
Key word:	exercise, cycling, cadence, near-infrared spectroscopy, tissue saturation index, muscle
Abstract:	<p>The aim of this study was to assess the changes determined by increased cadence on skeletal muscle oxygenation during cycling at exercise intensity equal to the ventilatory threshold (Tvent).</p> <p>Nine healthy, active individuals, with different levels of cycling experience, exercised at a power output equal to Tvent, pedalling at cadences of 40, 50, 60, 70, 80 and 90 rpm, each for 4 minutes. Cadences were tested in a randomized counterbalanced sequence. Cardiopulmonary and metabolic responses were studied using an ECG for heart rate, and gas calorimetry for pulmonary oxygen uptake and carbon dioxide production. NIRS was used to determine the tissue saturation index (TSI), a measure of vastus lateralis oxygenation.</p> <p>TSI decreased from rest to exercise; the magnitude of this TSI reduction was significantly greater when pedalling at 90rpm ($-14\pm 4\%$), compared to pedalling at 40 ($-12\pm 3\%$) and 50 ($-12\pm 3\%$) rpm ($P=0.027$ and 0.017, respectively). Albeit small, the significant decrease in ΔTSI at increased cadence recorded in this study suggests that skeletal muscle oxygenation is relatively more affected by high cadence when exercise intensity is close to Tvent.</p>

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1 The effect of pedalling cadence on skeletal muscle oxygenation during cycling
2 at moderate exercise intensity

6 Running title: Skeletal muscle oxygenation at different pedalling cadences

9 Key words: exercise, cycling, cadence, near-infrared spectroscopy, tissue
10 saturation index, muscle, oxygen

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view

Abstract

The aim of this study was to assess the changes determined by increased cadence on skeletal muscle oxygenation during cycling at exercise intensity equal to the ventilatory threshold (T_{vent}).

Nine healthy, active individuals, with different levels of cycling experience, exercised at a power output equal to T_{vent} , pedalling at cadences of 40, 50, 60, 70, 80 and 90 rpm, each for 4 minutes. Cadences were tested in a randomized counterbalanced sequence. Cardiopulmonary and metabolic responses were studied using an ECG for heart rate, and gas calorimetry for pulmonary oxygen uptake and carbon dioxide production. NIRS was used to determine the tissue saturation index (TSI), a measure of vastus lateralis oxygenation.

TSI decreased from rest to exercise; the magnitude of this TSI reduction was significantly greater when pedalling at 90rpm ($-14\pm 4\%$), compared to pedalling at 40 ($-12\pm 3\%$) and 50 ($-12\pm 3\%$) rpm ($P=0.027$ and 0.017 , respectively). Albeit small, the significant decrease in ΔTSI at increased cadence recorded in this study suggests that skeletal muscle oxygenation is relatively more affected by high cadence when exercise intensity is close to T_{vent} .

34 Introduction

35

36 The growing popularity of cycling is stimulating a wealth of research in the field of
37 exercise physiology beyond elite athletes' performance, with several studies
38 investigating the responses to exercise in recreational cyclists. The concurrent
39 advances in technological development allow for a variety of physiological
40 parameters to be studied *in vivo* and non-invasively.

41

42 Changing pedalling cadence during moderate intensity cycling affects a number of
43 physiological responses: at a constant and moderate power output, increasing
44 cadence causes an increase in heart rate (HR), oxygen consumption (VO_2), carbon
45 dioxide production (VCO_2), rate of perceived exertion and lactate
46 [11,16,20,31,32,38]. High pedalling cadences increase skeletal muscle metabolic
47 demand, which up to a point can be matched by a corresponding increase in the
48 cardio-respiratory function that raises the rate of pulmonary oxygen uptake and
49 oxygen delivery at systemic level. In contrast, low pedaling cadences increase
50 intramuscular pressure during the muscular contraction period [19], with a size effect
51 associated with the force generated by the muscular contraction [21]. This
52 phenomenon temporarily reduces or prevents blood perfusion to the contracting
53 muscle and downstream tissues. Inevitably during cycling exercise, low cadences
54 are also associated with proportionally longer muscular relaxation periods, when
55 perfusion is increased. It is currently unclear whether the longer contraction period
56 and greater pedal forces at lower cadence are likely to determine inadequate
57 oxygenation of the exercising muscles [34].

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3 59 The effect of pedalling cadence on skeletal muscle oxygenation has been rather
4
5 60 extensively explored in real time by means of near infrared spectroscopy (NIRS).
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7 61 This technique uses different wavelengths of infra-red light to estimate the
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9 62 haemoglobin and myoglobin in the tissue of interest, measuring their total changes
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11 63 (tHb), as well as the changes in the oxygenated (OxyHb) and deoxygenated forms
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13 64 (HHb). NIRS cannot detect differences between signals from haemoglobin and
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15 65 myoglobin, hence the contribution of myoglobin to the overall signal cannot be
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17 66 completely excluded. However, the hypothesis that most of the NIRS signal is
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19 67 determined by haemoglobin is supported by several observations [8,25,27,28,30,35].
20
21 68 Skeletal muscle oxygenation can then be expressed in terms of tissue saturation
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23 69 index (TSI), the ratio between OxyHb and tHb [9]. TSI provides an overall index of
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25 70 skeletal muscle oxygenation, while OxyHb and HHb estimate oxygen delivery and
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27 71 extraction at the tissue level respectively [14].
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35 73 When power output is increased during cycling exercise at a given pedalling
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37 74 cadence, HHb increases and skeletal muscle saturation decreases [3,4,10]. Not as
38
39 75 clear is the skeletal muscle oxygenation response to different pedalling cadences at
40
41 76 a constant power output. Skovereng et al. [31,32] reported that increasing cadence
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43 77 from 60 to 110 revolutions per minute (rpm), in an incremental sequence at a
44
45 78 workload equal to 70% of lactate threshold, decreased skeletal muscle oxygenation.
46
47 79 However, pedalling cadence had no significant effect on skeletal muscle oxygenation
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49 80 indexes during cycling, when cadences were tested in a randomised order at power
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51 81 outputs below the ventilatory threshold (T_{vent}). For example, Koulanakis and Geladas
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53 82 [24] reported no change in TSI between 40 and 80 rpm, when cadences were tested
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55 83 in a random sequence at a power output equal to 60% of VO_{2max} . Takaishi et al. [33]
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and Zorgati et al. [39] also reported no clear changes in oxygenation between cadences, when these were tested in a randomized sequence. These studies [24,31-33,39] do differ in terms of experimental design, including power output, cadence ranges and sequence in which they were tested, which may partly explain some differences in their findings. Numerous studies have also been performed to determine the optimal pedalling cadence for efficient cycling performance at a given power output. However, no clear consensus has been reached with some studies favouring a low cadence [23] and others a higher cadence [7], also highlighting the different responses observed between elite and recreational cyclists, where elite cyclists specifically train at high cadence [1,26,37]. Increasing cadence when exercising at T_{vent} may affect skeletal muscle oxygenation [15], yet no study to date has explored the effect of altering cadence on TSI when cycling at T_{vent} .

In this context, the aim of our study was to investigate the effects of different pedalling cadence on the systemic and *vastus lateralis* oxygenation responses to cycling at a constant power output equal to 100% of the T_{vent} in participants with different levels of cycling experience. We hypothesised that skeletal muscle oxygenation would be lower both at the low (40 rpm) and high (90 rpm) cadences, due to the effects of intermittent blood perfusion and insufficient oxygen delivery-to-uptake ratio, respectively.

Materials and Methods

109 **Participants**

110 The study received ethical approval from the institutional review board of the Nagoya
111 University Graduate School of Medicine (approval no. 2016-0531), and conformed to
112 the standards outlined in the Declaration of Helsinki and to the standards for ethics in
113 sport and exercise science research [18]. Each participant gave her/his informed
114 consent before taking part in the study. Nine healthy participants (male/female = 6/3)
115 were recruited and completed the study. In terms of their activity levels, two
116 participants were triathletes at regional level with three-year experience, six regularly
117 engaged in moderate and vigorous exercise, and one engaged with very light
118 physical activity only occasionally [12]. The participants' age ranged from 21 to 55
119 years.

122 **Experimental Protocol**

123 *Estimation of ventilatory threshold*

124 The ventilatory threshold for all of the participants was measured with an incremental
125 ramp test. Participants cycled at 60 rpm against an external power output starting at
126 20 W or 30 W for female and male participants respectively (mean \pm SD; starting
127 power output 28 ± 4 W). The external power output increased by 10, 15, 20, 25 W
128 min^{-1} depending on the estimated fitness of the participant tested (rate of external
129 power output increase 20 ± 6 W min^{-1}), aiming for a total duration of the test of
130 around 10 minutes [2,5]. The T_{vent} of each participant was estimated using the V-
131 slope method [22], ventilatory equivalent of oxygen method (VE/VO_2) [36] and
132 ventilatory equivalent of carbon dioxide method (VE/VCO_2) [6]. The mean value is
133 then taken from these four methods and used as an estimation of the participant's

134 T_{vent} . This approach has been shown to increase the precision of T_{vent} estimations,
135 when compared with using just one of these methods alone [13].

136

137 *Responses to different cadences*

138 A schematic diagram of the protocol where responses to different cadences were
139 studied is presented in **Figure 1**. After 2 min of rest, participants warmed up for 6
140 min, pedalling at 60 rpm while external power output increased every 2 min in steps
141 to 25%, 50% and 75% of the power output calculated for T_{vent} . Participants were then
142 asked to cycle at an external power output equal to their T_{vent} at cadences of either
143 40, 50, 60, 70, 80 or 90 rpm, when real-time cadence was displayed on a digital
144 monitor visible to the participant and a metronome was used in order to help the
145 participants achieve the desired cadence.. Cadences were tested in a randomized,
146 counterbalanced sequence (with 90 rpm always tested last to reduce the potential
147 effect of fatigue). Participants exercised at each cadence for 4 min, immediately
148 followed by 2 minutes of active recovery, cycling at 60 rpm at 25% of T_{vent} . These
149 active recovery periods allowed TSI to return closer to initial values and to reduce
150 the potential effects of fatigue over the course of the experimental protocol.

151

152 Pedalling cadence, expired gases, heart rate and *vastus lateralis* oxygenation were
153 continuously recorded. Blood lactate was recorded in the last 90 s of the initial rest
154 period and of each 4 min bout of cycling exercise at 100% T_{vent} .

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156

157 *Equipment*

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159 *Cycle ergometer and pedal force measurements*

160 An electronically braked cycle ergometer (Aerobike 75XL, Combi, Tokyo, Japan) was
161 used for all experiments. The external power output could be set to the nearest 1 W,
162 using personalized, pre-programmed protocols.

163
164 Pedal force was recorded using three miniature force transducers (LM-50KA, Kyowa
165 Dengyo, Tokyo, Japan) on the pedal and a DC amplifier (DPM-601A, Kyowa
166 Dengyo, Tokyo, Japan). Three force signals were converged to one signal and
167 calculated the pedal force perpendicular to the pedal. Peak force was calculated for
168 each cycle. Pedal cadences were calculated using the principle of electromagnetic
169 induction by four small magnets on the gear and coil. The system generated four
170 peak voltage signals at each pedal revolution, so that cadence can be precisely
171 calculated.

172
173 We recorded pedal force and, importantly, pedalling cadence during each
174 experiment in order to establish participants' protocol adherence or deviations from
175 the expected cadence.

177 *Cardiopulmonary responses and rate of perceived exertion measurements*

178 Heart rates were measured continuously during all stages of the trials by means of a
179 three-lead electrocardiogram (AB-621G, Nihon Kohden, Tokyo, Japan) connected
180 using gel electrodes applied to the skin. All analyzed data were linearly interpolated
181 between each cycle or heart beat to yield a data point at each 1 s interval.

183 Respiratory and metabolic data were recorded with the ARCO-2000 (Arco System
184 Inc., Chiba, Japan) with a mass spectrometer and a Fleisch pneumotachometer.
185 Participants wore a facemask (7450, Hans-Rudolph Inc., MO, USA) with dead space
186 of ~100 ml.

188 Participant's rate of perceived exertion was recorded on a standard Borg scale table
189 just after the end of each exercise bout (Borg, 1982).

191 *Blood lactate concentration*

192 Blood lactate concentration values were recorded using the Lactate Pro 2[®] analyser
193 (HaB International Ltd., England). Before taking a reading, the finger was cleaned
194 with an alcohol swab (70% Isopropyl alcohol) and wiped with a tissue to avoid
195 alcohol contamination of the sample.

197 *Skeletal muscle (vastus lateralis) oxygenation*

198 Participants' muscle oxygenation values (OxyHb, HHb, tHb, TSI) were sampled at 10
199 Hz using the PortaMon[®] (Artinis Medical Systems, Einsteinweg, The Netherlands)
200 [29]. Briefly, the NIRS device was positioned on the participant's skin over the
201 muscle belly of the right *vastus lateralis*, along the main axis of the thigh,
202 approximately 16 cm from the knee joint. The device was secured using a Velcro
203 strap to prevent the device from moving during the experiment and to cover the
204 sensors, ensuring no ambient light contaminated the NIRS signal.

207 **Data Analysis**

Analyses were performed for peak pedal force, pedalling cadence, heart rate, blood lactate, RPE, VO_2 , VCO_2 , OxyHb, HHb, tHb and TSI. Mean \pm standard deviation values at each cadence during the 100% T_{vent} tests were calculated from the last 60 s of each cycling bout in Microsoft Excel (Version 15.25.1, Microsoft Corporation, California, USA).

SigmaPlot (13.0.0.83, Systat Software, Inc., San Jose, California, USA) was used for statistical analysis. The Shapiro-Wilk test was used to check for normal distribution of the data. The Brown-Forsythe test was conducted to test for equal variance. Data for physiological variables at different cadences were analysed using a One Way Repeated Measures Analysis of Variance (ANOVA), if they passed the normality tests. A Bonferroni pairwise multiple comparison procedure was used as a post-hoc test to compare the means of each cadence.

RPE and VO_2 data did not pass the Shapiro-Wilk and Brown-Forsythe tests, so a Friedman's one way repeated measures ANOVA based on ranks and Tukey's post hoc test were performed to test for differences between responses at each cadence. Results are presented as mean \pm standard deviation unless otherwise stated. Statistical significance was set at $P < 0.05$ for all tests.

Results

Participants' characteristics and protocol adherence

Six male and three female participants took part in this study. The characteristics of these participants are presented in **table 1**. The recorded cadences matched the required cadences well, as presented in **table 2**.

Changes in cardiorespiratory and metabolic function, perceived exertion and pedal force at different pedalling cadences

Figure 2 shows the physiological, metabolic, rate of perceived exertion and peak pedal force values at the different pedalling cadences recorded at at 100% T_{vent} . HR (Figure 2A), VO_2 (Figure 2C), VCO_2 (Figure 2D) and peak pedal force (Figure 2F) changed significantly at the higher pedalling cadences when compared to the lower pedalling cadences ($P < 0.05$). The respiratory rate did not increase significantly between 40 and 90 rpm (30 ± 5 and 31 ± 4 breaths per minute respectively, $p = 0.09$), unlike tidal volume and ventilation that increased respectively from 1.7 ± 0.5 L to 2.0 ± 0.5 L ($p = 0.0001$) and from 50 ± 17 L/min to 62 ± 21 L/min ($p = 0.0002$). A significant but small increase in blood lactate concentration was recorded at 60 rpm (Figure 2B). No significant or marked changes were seen in RPE at the different pedalling cadences (Figure 2E).

Changes in skeletal muscle oxygenation at different pedalling cadences

Figure 3 shows the changes in skeletal muscle oxygenation in the *vastus lateralis* muscle at different pedalling cadences. OxyHb and TSI decreased from resting levels (Figure 3A and 3D), while HHb and tHb levels increased from their resting values (Figure 3B and 3C). TSI was not different in the 30 s preceding each cadence

test ($p = 0.86$), with SD values $\sim 1\%$ for each individual. The magnitude of the TSI reduction was significantly greater when pedalling at 90 rpm ($-14.6\% \pm 4$), compared to pedalling at 40 ($12.3\% \pm 3$) and 50 ($-12.2\% \pm 3$) rpm ($P = 0.027$ and 0.017 , respectively).

Discussion

In our study of participants with different cycling expertise, pulmonary oxygen uptake recorded at the highest cadence of 90 rpm was greater than at lower cadences during exercise at $100\% T_{vent}$. This greater pulmonary oxygen uptake was associated with a 3% greater TSI decrease at high cadence of 90 rpm compared with low cadences of 40 and 50 rpm.

Increased pedalling cadence at constant power output of $100\% T_{vent}$ resulted in a greater cardiorespiratory response

Both the cardiovascular and respiratory systems' function increased at the higher cadence of 90 rpm, in order to meet the increased metabolic demands of the exercising muscles. These cardiopulmonary results are in agreement with previous findings and suggest that skeletal muscle oxygenation may also be affected at the high cadence. The extra work at higher cadence is associated with a greater oxygen demand (extraction); when this oxygen demand exceeds oxygen supply (delivery) beyond a given threshold, TSI may decrease, as observed at high cadences in our study.

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283

284 ***Skeletal muscle oxygenation at high cadence when pedalling at constant***

285 ***power output***

286 Changes in HHb are considered a good indicator of skeletal muscle oxygen
287 extraction because the HHb signal is not affected by an increase in oxygenated
288 blood to the skin for thermoregulation [14]. HHb tended to increase from baseline
289 levels during cycling at 100% T_{vent} , indicating a moderate increase in fractional
290 oxygen extraction in the exercising muscles, achieved via an increase in cardiac
291 output and/or a reduction in the peripheral vascular resistance at the exercise
292 intensity tested.

293

294 Despite these changes from baseline and a trend for an increase in HHb and tHb at
295 high cadence, there was no significant change in these skeletal muscle oxygenation
296 parameters between the pedalling cadences. These findings are in agreement with
297 previous studies, which reported that cadence had no clear effect on OxyHb, HHb
298 and tHb in conditions similar to those tested here [24,39].

299

300 TSI is an overall indicator of skeletal muscle oxygenation [14,17]. TSI significantly
301 decreased from baseline during cycling exercise at 100% T_{vent} , and from 40 and 50
302 rpm to 90 rpm (Figure 3D). The significant changes in TSI observed at higher
303 pedalling cadences, which we tested in a randomized sequence at 100% T_{vent} , are in
304 agreement and strengthen the findings from Skovereng et al. [31,32]. These results
305 are supported by previous observations at a relatively lower power output equal to
306 60% of VO_2max , where skeletal muscle oxygenation was not different at the onset of

cycling exercise at either 40 or 100 rpm [24], confirming our results in an acute exercise context.

It is likely that the effect of intramuscular pressure on TSI is associated with the absolute pressures generated during the contraction. Given the higher external power output at which elite cyclists exercise (for a similar relative exercise intensity, e. g. 100% T_{vent}), these absolute intramuscular pressures are likely to be greater in elite than in recreational cyclists. This is a putative mechanism that could explain the difference in our findings with those reported in trained cyclists by Skovereng et al., where TSI decreased at high cadence even at a lower relative external power output corresponding to 75% of the participants' lactate threshold [31,32].

The group of participants studied was limited to nine individuals and rather heterogeneous in terms of age, exercise capacity and cycling expertise. Given the limited sample size considered in this study, we acknowledge that this finding needs confirmation on a larger scale.

A limitation of our study is that the T_{vent} was estimated at one pedalling cadence only. It is possible that estimating T_{vent} at higher or lower pedalling cadence could have affected the estimated T_{vent} . For the incremental test, we chose a cadence that all participants could exercise at comfortably, and that has been used in several published studies before, making our results comparable with those presented in the literature. In addition, there is often a degree of error in the estimation of T_{vent} , so we think that the estimated T_{vent} would have only varied significantly if cadence had

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markedly been reduced or increased from 60 rpm. An additional limitation is in the choice of testing the highest cadence (i. e. 90 rpm) always last, where it cannot be entirely excluded that the results associated with the 90 rpm conditions are in part determined by the preceding exercise. However, TSI was not different (within participant) between rest and the final part of each recovery period, so the likelihood of TSI decrease observed at 90 rpm being determined by the preceding exercise appears limited.

We conclude that increasing cadence beyond a given threshold at moderate exercise intensity close to the T_{vent} is less energetically efficient (as confirmed by the higher VO_2 and VCO_2 recorded for a given power output here [Fig. 2]) and that high cadence may compromise skeletal muscle oxygenation during cycling exercise.

Disclosure of interest: The authors report no conflict of interest.

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Figure captions

Figure 1. Schematic representation of the experimental protocol. Participants pedalled at 60 rpm during the warm-up and 2 min active recovery periods. **A:** Rest period, **B:** warm-Up period (6 min), **C:** 100% T_{vent} exercise bout at a given cadence (4 min), **D:** active recovery period (2 min). T_{vent} : ventilatory threshold; rpm: revolutions per minute; min: minutes.

Figure 2: Physiological responses to cycling exercise at different pedalling cadences.

Values for (A) heart rate (bpm), (B) lactate concentration (mM), (C) VO_2 (ml/kg/min), (D) VCO_2 (ml/kg/min), (E) RPE and (F) peak pedal force (N) for each cadence at 100% T_{vent} ($N = 9$). Lactate concentrations greater than 8 mM ($n = 3$ out of 63) were considered as technical errors and excluded from the analysis.

a, b, c, d, e: $P < 0.05$ when compared to 40, 50, 60, 70 and 80 rpm respectively, at the same T_{vent} . min: minutes; bpm: beats per minute; rpm: revolutions per minute; T_{vent} : ventilatory threshold; VO_2 : pulmonary oxygen uptake; VCO_2 : carbon dioxide output; RPE: rate of perceived exertion; AU: arbitrary units.

Figure 3: Skeletal muscle oxygenation responses to cycling exercise at different cadences. Results are of changes from rest for (A) OxyHb, (B) HHb, (C) tHb and (D) TSI for each cadence performed at 100% T_{vent} . For OxyHb, HHb and

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3 486 tHb (A, B and C) N = 8 for changes from baseline (due to one missing baseline data
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5 487 set). For each 90 rpm data set N = 7 (due to one missing data set at this cadence).
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8 488 a, b: $P < 0.05$ when compared to 40 and 50 rpm respectively, at the same T_{vent} . min:
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10 489 minutes; AU: arbitrary units; TSI: tissue saturation index; OxyHb: oxygenated
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12 490 haemoglobin; HHb: deoxygenated haemoglobin; tHb: total haemoglobin; T_{vent} :
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14 491 ventilatory threshold; rpm: revolutions per minute.
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For Peer Review

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Parameter	N = 9
Age (years)	29 ± 11
Height (m)	1.70 ± 0.07
Weight (kg)	62 ± 10
BMI (kg m ²)	21.5 ± 2.5
Power output at T _{vent} (W)	125 ± 44
VO ₂ at T _{vent} (ml/kg/min)	25 ± 9
Baseline TSI (%)	72 ± 5

Table 1. Participants’ demographic data. The large standard deviation value for the power output at T_{vent} (range from 80 to 200 W) indicates a wide variety of exercise capacity across the participants’ group. TSI: tissue saturation index; T_{vent}: ventilatory threshold.

Required cadence (rpm)	Recorded cadence (rpm)
40	41 ± 2
50	50 ± 2
60	60 ± 1
70	70 ± 2
80	79 ± 3
90	89 ± 3

Table 2. Required and recorded cadences. The participants were instructed to cycle at cadences of 40, 50, 60, 70, 80 and 90 rpm for 4 min bouts during the trial. The table shows the required cadence and cadence recorded during each exercise bout. rpm: revolutions per minute.

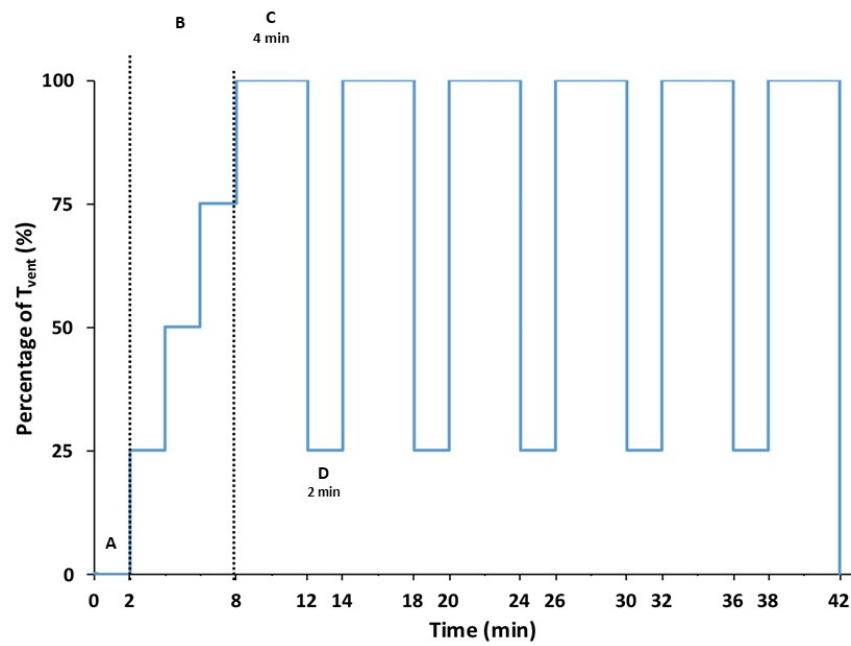


Figure 1: Schematic representation of the experimental protocol. Participants pedalled at 60 rpm during the warm-up and 2 min active recovery periods. A: Rest period, B: warm-Up period (6 min), C: 100% Tvent exercise bout at a given cadence (4 min), D: active recovery period (2 min). Tvent: ventilatory threshold; rpm: revolutions per minute; min: minutes.

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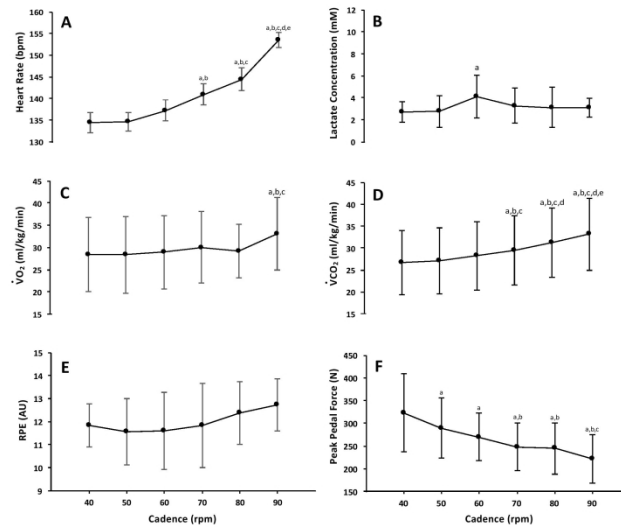


Figure 2: Physiological responses to cycling exercise at different pedalling cadences.

Values for (A) heart rate (bpm), (B) lactate concentration (mM), (C) VO₂ (ml/kg/min), (D) VCO₂ (ml/kg/min), (E) RPE and (F) peak pedal force (N) for each cadence at 100% Tvent (N = 9). Lactate concentrations greater than 8 mM (n = 3 out of 63) were considered as technical errors and excluded from the analysis.

a, b, c, d, e: P < 0.05 when compared to 40, 50, 60, 70 and 80 rpm respectively, at the same Tvent. min: minutes; bpm: beats per minute; rpm: revolutions per minute; Tvent: ventilatory threshold; VO₂: pulmonary oxygen uptake; VCO₂: carbon dioxide output; RPE: rate of perceived exertion; AU: arbitrary units.

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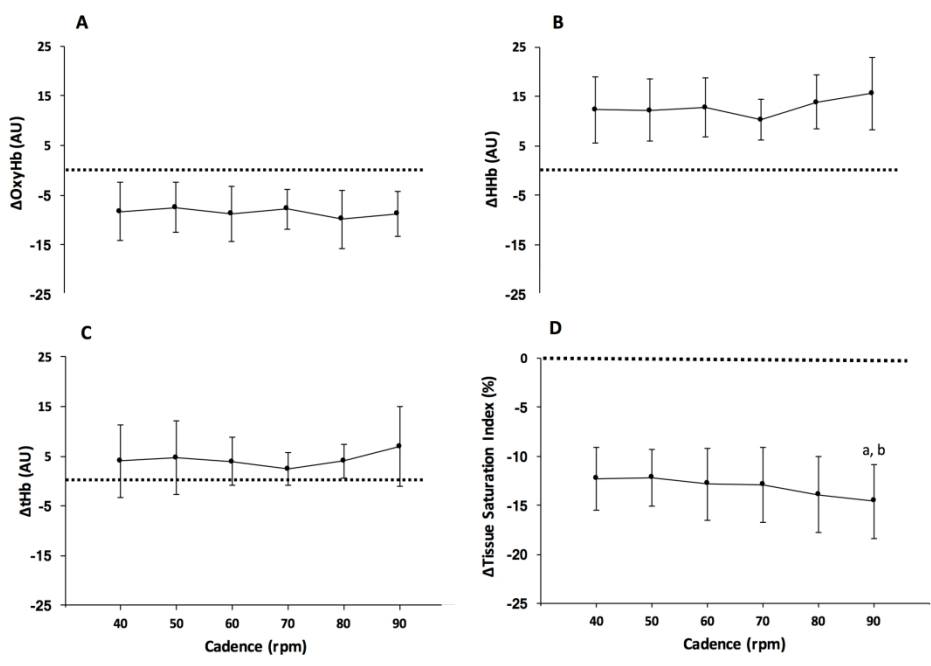


Figure 3: Skeletal muscle oxygenation responses to cycling exercise at different cadences. Results are of changes from rest for (A) OxyHb, (B) HHb, (C) tHb and (D) TSI for each cadence performed at 100% Tvent. For OxyHb, HHb and tHb (A, B and C) N = 8 for changes from baseline (due to one missing baseline data set). For each 90 rpm data set N = 7 (due to one missing data set at this cadence). a, b: P < 0.05 when compared to 40 and 50 rpm respectively, at the same Tvent. min: minutes; AU: arbitrary units; TSI: tissue saturation index; OxyHb: oxygenated haemoglobin; HHb: deoxygenated haemoglobin; tHb: total haemoglobin; Tvent: ventilatory threshold; rpm: revolutions per minute.

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